Telecommunications

1 Sending a Signal

The transmission of signals falls under the branch of **telecommunications**. Let's suppose we transmit a signal in all directions. This is done by a so-called **isotropic antenna**. The **transmitter power** P sadly isn't the power that is being emitted. There is so-called **line loss**, designated by the factor L_l. This line loss is similar to an efficiency. It is defined such that the emitted power is equal to PL_i. The power per square meter that a receiver at a distance S from the transmitter receives W_f (the so-called **power flux density**), is then given by

$$W_f = \frac{PL_l}{4\pi S^2}. \tag{1.1}$$

It is of course more efficient to send the signal only in the direction of the receiver. We therefore send the signal only to a certain **coverage area**. Now the **antenna gain** is defined as

$$G_t = \frac{\text{Power radiated to the center of the coverage area}}{\text{Power radiated by an isotropic antenna}}. \tag{1.2}$$

Once more an additional factor L_a (now called the **transmission path loss**) needs to be added. The power flux density becomes

$$W_f = \frac{PL_tG_tL_a}{4\pi S^2} = \frac{\text{EIRP}\, L_a}{4\pi S^2}, \tag{1.3}$$

where the EIRP $= PL_lG_t$ is the **effective isotropic radiated power**.

2 Noise

When sending a signal, there is often **noise**. This noise can come from the electronic circuit, from distortions in the radio signal, or from other sources. **Electrical noise** comes from random thermal motions of atoms in the circuit. This thermally generated electrical power is the **noise power spectral density** N_0. It can be found by using

$$N_0 = kT_s, \tag{2.1}$$

where $k = 1.38 \cdot 10^{-23} J/K$ is a constant and T_s is the system temperature. The total **received noise power** N can then be found by multiplying N_0 by the **frequency band** B (in Hz). So we find that

$$N = N_0B. \tag{2.2}$$

Amplifiers are often used to increase the power of a signal. The signal has a certain power P_{in} as it enters the amplifier, and a different power P_{out} as it exits it. The **amplifier gain** G is the found using

$$G = \frac{P_{out}}{P_{in}}. \tag{2.3}$$

The noise of the signal as it enters the amplifier is $N_{in} = kT$. Under ideal circumstances, the noise that comes out of the amplifier is $N_{out} = GkT$. This is however never the case. The noise that comes out of the amplifier is always bigger. Therefore a so-called **amplifier noise temperature** T_n is introduced, such that

$$N_{out} = Gk\left(T + T_n\right). \tag{2.4}$$

3 Receiving a Signal

How much power does the receiver receive? First we need to know the the diameter of the receiving device D_r. Then the total receiving area is $\pi D_r^2/4$. This isn't the area that is useful, so an efficiency η needs to be added. The **effective receiver aperture area** then becomes

$$A_r = \frac{1}{4}\pi D_r^2 \eta. \tag{3.1}$$

The **received power** C is now given by

$$C = W_f A_r = \frac{P L_l G_t L_a D_r^2 \eta}{16 S^2}. \tag{3.2}$$

We can write the previous equation slightly different, by using a second type of antenna gain. This gain, denoted by G_r, is defined as

$$G_r = \left(\frac{\pi D_r^2 \eta}{4}\right)\left(\frac{4\pi}{\lambda^2}\right) = \frac{\pi^2 D_r^2 \eta}{\lambda^2}. \tag{3.3}$$

If we now also define the **space loss** L_s as

$$L_s = \left(\frac{\lambda}{4\pi S}\right)^2, \tag{3.4}$$

then the received power will be

$$C = P L_t G_t L_s L_a G_r. \tag{3.5}$$

A digital signal is send by using bits. The number of bits per second is the **data rate** R. The received energy per bit can then be found by

$$E_b = \frac{C}{R}. \tag{3.6}$$

Now the so-called **link budget** E_b/N_0 can be found using

$$\frac{E_b}{N_0} = \frac{C}{N_0 R} = \frac{P L_t G_t L_s L_a L_{pr} G_r L_r}{k T_s R}. \tag{3.7}$$

Note that the variables L_{pr} and L_r have appeared out of nowhere. They are two more loss factors. L_{pr} is the **antenna pointing error** and L_r is the **antenna loss**.

4 Decibels

Multiplying numbers is sometimes difficult. Adding up numbers is a lot easier. Therefore the **decibel** (unit dB) is often used in communications. We can set the unit of a parameter X to dB using

$$X_{dB} = 10 \log_{10} X. \tag{4.1}$$

If we would apply this to the right hand side of the link budget equation, we would get

$$P_{dB} + L_{l_{dB}} + G_{t_{dB}} + L_{pr_{dB}} + L_{s_{dB}} + L_{a_{dB}} + G_{r_{dB}} + L_{r_{dB}} - k_{dB} - T_{s_{dB}} - R_{dB}. \tag{4.2}$$

However, it does make a difference whether you take a decibel from a variable in W or in mW. Therefore there are more specific decibel-units. The most used are the dBW (the decibel-Watt) and the $dBmW$ (the decibel-mW, also written as dBm). Keep this in mind when working with decibels.

5 Modulation

Modulation means joining the info of a low-frequency signal with that of a high-frequency signal. The low-frequency signal is called the **modulating signal**. The high-frequency signal is the **carrier signal**. The signal is modulated at the transmitter side, and then demodulated at the receiving side. **Demodulation** means that the low-frequency signal is recovered.

We can make a distinction between **analog-analog modulation**, **digital-analog modulation**, **analog-digital modulation** and **digital-digital modulation**. The first term indicates the modulating signal type, while the second term indicates the carrier signal type.

We primarily look at analog-analog modulation. The carrier signal here is given by

$$V_c = A_c \cos\left(2\pi f_c t + \phi_c\right), \tag{5.1}$$

where A_c is the **amplitude**, f_c is the **frequency** and ϕ_c is the **phase**. Identically, the modulating signal is given by

$$V_m = A_m \cos\left(2\pi f_m t + \phi_m\right). \tag{5.2}$$

This gives rise to three types of analog modulation, being **amplitude modulation** (AM), **frequency modulation** (FM) and **phase modulation** (PM). In amplitude modulation, we change the amplitude of the carrier signal to

$$A_c + V_m. \tag{5.3}$$

So the modulating signal is hidden in the amplitude of the carrier signal. In frequency modulation, the modulating signal is hidden in the (constantly changing) frequency of the carrier in a similar way. Finally, in phase modulation the modulating signal is hidden in the phase of the carrier signal.

In digital-analog modulation there are also several types. There is **amplitude shift keying** (ASK), **frequency shift keying** (FSK) and **phase shift keying** (PSK). In the latter one are several more variations, of which **binary phase shift keying** (BPSK) and **quaternary phase shift keying** (QPSK) are the most familiar (or the leased unfamiliar) types. Finally, there are more complex modulations possible. Although complex modulations can increase the information-carrying capacity of a channel, it often also leads to an increase in errors.

6 Coding

Coding a signal is changing it to a more useful form. There are three branches of coding. In **encryption** you give unwanted listeners a hard time understanding your message. In **compression** you use tricks to reduce the size of your message. Finally, there is **adding redundancy**, which is what we will look at in this chapter.

When sending a digital signal, errors occur. If an error occurs in a digital signal, this usually means that a bit has changed value. The bit will be erroneous. To indicate the quality of the signal, the **bit error rate** (BER) is defined as

$$\text{BER} = \frac{\text{\# of bits recieved in error}}{\text{\# of bits transferred}}. \tag{6.1}$$

The chance that a bit gets corrupted is then simply equal to the BER. The chance that an entire message of N bits has no errors then is

$$P_{success} = \left(1 - \text{BER}\right)^N. \tag{6.2}$$

For high N, the chance of a message without errors decreases rapidly.

To decrease the chance of an erroneous message, you add redundancy to the system. In **channel coding** (also called **error coding**) you add bits such that errors can be detected or even corrected. In a **bi-directional** system errors can only be detected, while in a **uni-directional** system they can also be fixed. **Forward error coding** (FEC) is the most used form of uni-directional coding.

One way to implement FEC is by using **block coding**. Here you change every message piece (called the word) by a different longer piece (called the codeword). This is done in such a way that no two codewords are similar. Even if one bit changes in a codeword, it is still clear what the original codeword was.

Another method is the **Reed-Solomon code** (RS). When applying this method, often the amount of **message bytes** and **parity bytes** are noted. A (64,40) RS code has a total size of 64 bytes. The message consists of 40 bytes. The remaining 24 bytes are present for error detection and correction.

Another method is **convolutional coding**. The decoder of a convolutional coded stream of bits is called a **Viterbi decoder**. Convolutional coding is more suitable for serial data, encoding a few bits at a time. Read Solomon coding is more suited for big blocks of data.

7 Multiple Access

Sometimes multiple persons want to use the same line. How do you then share communication links? There are three ways for this.

In **time division multiple access** (TDMA) all users use the same frequency channel. Each user then gets a certain time slot in which he can use the connection. In this way every user can use the channel with a very high efficiency. However, much communication time gets wasted in this way.

In **frequency division multiple access** (FDMA) each user gets a discrete part of the spectrum, thus operating at a different frequency than the others. Although each user can continuously transmit, there is often interference and low power efficiency. It is also hard to separate the channels.

In **code division multiple access** (CDMA) everyone transmits all the time at the same frequency. Every user has its own pseudo random noise code (PN code). Because of this, the entire signal just looks like noise. However, by multiplying this signal by the right PN code, the correct signal can be extracted. This is called **de-spreading**. This method may have no interference, but the number of users and the data rates are quite limited.

Instead of always operating on the microwave frequencies, it is also possible to use **optical frequencies**. Due to clouds, this is usually an unreliable option for Earth-satellite communication. However, for inter-satellite communication it has a lot of advantages. One of the most important ones is the very high data rates that can be acquired. Accurate pointing of the signal is required though, and this can sometimes be difficult.